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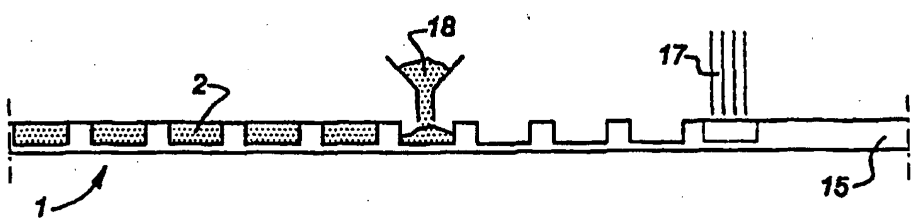

(57) Abstract

The present invention relates to a method of manufacturing a substantially planar substrate (1), formed of at least a first and a second material (3, 4) having substantially different conductivities, such that conductive channels (2) are formed substantially perpendicular to the substrate surfaces, and the conductivity perpendicular to the substrate surfaces, as measured over a predetermined area, is substantially larger than the conductivity parallel to the substrate surfaces. Furthermore, the invention refers to a display device (23) comprising at least one substrate (1) manufactured according to the present method, an optically active layer (8; 24), and at least one control electrode (10), thereby enabling the provision of a local electrical field over the optically active layer (8; 24).

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METHOD FOR PRODUCING A SUBSTRATE WITH UNDIRECTIONAL CONDUCTIVITY AND DISPLAY DEVICE USING SUCH A SUBSTRATE IN AN ANISOTROPIC CONTACT LAYER

The present invention relates to a method of manufacturing a substantially planar substrate with a predetermined substrate thickness, having a first substrate surface and a second substrate surface extending substantially in parallel to the first substrate surface, and being formed of at least a first and a second material having substantially different conductivities, such that conductive channels are formed substantially perpendicular to the substrate surfaces, and the conductivity perpendicular to the substrate surfaces, as measured over a predetermined area, is substantially larger than the conductivity parallel to the substrate surfaces. The present invention further relates to display devices using the substrate with unidirectional conductivity.

Manufacturing of such substrates with unidirectional conductivity are e.g. known from PCT/NL98/00341, which has not yet been published, from the same applicant as the present application, which is included herein by reference.

For certain applications, a further insulation layer is added to the substrates with unidirectional conductivity during further processing. These insulation layer are e.g. used in the manufacturing of liquid crystal displays (LCD) to protect against a short-circuit situation when conductors on either side of the LC layer are pressed together. For proper functioning of an LCD, a very thin insulating layer is required. The addition of such a very thin insulation layer further complicates the manufacturing process of numerous applications of the substrate with unidirectional conductivity, e.g. the manufacturing of LCD's.

Therefore, the object of the present invention is to provide a method for manufacturing substrates with unidirectional conductivity characteristics, including a very thin insulation layer, which is more simple and cost-effective than separately applying insulation layers.

This object is obtained by the method as described in the preamble, in which the method further comprises the steps of:

- providing a layer of the first material with a predetermined thickness, having a first surface forming the first substrate surface;

- forming cavities in the first material in a predetermined pattern across a second surface of the first material, in which the cavities extend in a direction substantially perpendicular to the first surface over a predetermined depth; and

- applying the second material on the second surface of the first material until the cavities are at least filled, thereby forming the second surface of the substrate.

The method according to the present invention has the advantage that a substrate with the required characteristics (unidirectional conductivity, very thin insulation layer) can be manufactured simply, requiring only a few production steps which are well known in the art. The further handling of these substrates is also simpler than the handling of both substrates with unidirectional conductivity and insulating layers in the same production process.

In a further embodiment of the method according to the present invention, the first material is an insulating material with a thickness equal to the substrate thickness and the cavities are manufactured to extend to a depth smaller than the thickness of the first material. In this embodiment the very thin insulating planar layer of the substrate is formed by the remaining material of the first layer after formation of the cavities.

In a still further embodiment of the method according to the present invention, the second material is an insulating material and the method further comprises the steps of:

- applying the first material on a supporting structure with a thickness of less than the substrate thickness;

- manufacturing the cavities such that the depth of the cavities is equal to the thickness of the first material;

- applying the second material until the substrate reaches the predetermined thickness;

- forming the substrate by removing the supporting structure.

In this embodiment, the insulating layer is formed by the application of the second material to an extent that not only the cavities are filled, but also a thin insulating layer is formed on top of the substrate.

The present methods can also be used to manufacture substrates with optically active material, such as liquid crystal. By filling the cavities in an insulating layer with optically active material, or by

forming columns of optically active material and subsequently filling the spaces in between with insulating material, substrates may be formed with a predetermined pattern of optically active cells. This method of manufacturing optically active substrates is both simple and renders a large degree of freedom in defining the shape of the individual optically active cells and the pattern of optically active cells.

In a preferred embodiment the cavities in the layer of a first material are provided by etching techniques. As an alternative, laser beam evaporation or laser beam cutting can be used to provide the cavities in the first material.

A further object of the invention is to provide a method for producing a substrate in a simple and cost effective manner, which substrate can be used to provide an electric field distribution on the first surface of the substrate by locally applying a voltage on the second surface of the substrate with a local maximum value directly opposite a the locally applied voltage and decreasing value with increasing distance from the local maximum. This object is obtained by the method of manufacturing a substantially planar substrate with a predetermined substrate thickness, having a first substrate surface and a second substrate surface extending substantially in parallel to the first substrate surface, characterised in that the method comprises the steps of:

- producing spheres of a first, conductive material;
- coating the spheres with a thin layer of a second, insulating material;
- providing an insulating polymer, and distributing the coated spheres homogeneously in the insulating polymer;
- producing the substrate from the polymer containing the spheres.

Although this substrate is not suited for applications requiring a strict unidirectional conductivity to control an optically active layer, it can be used for applications which require a less strictly defined resolution and sharpness of the unidirectional conductivity, e.g. applications of the substrate in display devices with large dimensions.

A still further object of the invention is to provide display devices using the substrate manufactured according to one of the embodiments of the present invention.

This object is obtained by a display device comprising at least a first substrate manufactured according the present invention and a layer of conductive material substantially parallel to the first substrate, the display device further comprising an optically active layer positioned between the first substrate and the conductive layer, and at least one control electrode electrically connected to a surface of the first substrate opposite the optically active layer, thereby enabling the provision of a local electrical field over the optically active layer.

As an alternative, a display device is provided in which the layer of conductive material is formed by a second substrate manufactured according to one of the methods according to the present invention. The display device is provided with a plurality of further control electrodes on a surface of the second substrate opposite the optically active layer.

According to an embodiment of the display device according to the present invention, the optically active layer comprises dipole spheres with semispheres of a first and second colour, respectively, which dipole spheres can be aligned by the local electrical field, such that the semispheres of the first or second colour are aligned in the same direction.

An alternative embodiment of the display device according to the present invention comprises a layer of microcontainers filled with charged particles, which particles are moveable by the local electrical field.

A further alternative embodiment of the display device according to the present invention comprises an optically active layer formed by an electrocapillary sheet with electrocapillaries, in which a polarized fluid is contained in the electrocapillaries, which fluid can be displaced under the influence of an electric field.

In a still further embodiment of the display device according to the present invention, the optically active layer comprises double-funnel shaped pixels comprising two funnels, in which narrow parts of the funnels are connected to each other, in which the pixels are filled with a fluid, containing electrically charged particles, which

can be displaced through the funnels under the influence of an electric field.

A further aspect of the present invention concerns a display device comprising a first and a second substrate manufactured according to one of the claims 1 through 10, in which the first and second substrate are positioned substantially parallel to each other, an optically active layer is positioned between the first and second substrate, and a number of conductors are provided on the outside surfaces of the first and second substrate, thereby enabling the provision of a local electrical field in the optically active layer, characterised in that the optically active layer comprises a number of pixels comprising at least one flexible member of a first colour, at least one expandable member comprising at least an electrically driven chemomechanical polymer gel, and a fluid, which expandable member is arranged to press the flexible member against the second substrate under the influence of the local electrical field. Because the flexible member can be pressed against the first or second substrate, it is possible to provide a display device with a high degree of colour saturation.

The present invention also refers to the use of an electrically driven chemomechanical polymer gel to alter optical properties of a device provided with a flexible optical member, e.g. a flexible polymer lens, of which the optical properties may be altered by electrically driven chemomechanical polymer gel provided on the perimeter of the flexible lens.

The present invention will now be described in more detail, referring to the accompanying drawings, in which:

Fig. 1 shows a cross-sectional view of a substrate manufactured according to a preferred embodiment of the present;

Fig. 2 shows a phase of the production of a substrate with unidirectional conductivity according to a preferred method;

Fig. 3 shows the electrical equivalent of one conductive column, the insulation layer and a liquid crystal layer, driven by an electrical source;

Fig. 4 shows an assembly of a substrate manufactured according to the present invention, provided on a first side of an LC layer, with the insulating side of the substrate contacting the LC layer;

Fig. 5 shows an illustration of an alternative method for manufacturing the substrate according to an embodiment of the present invention;

Fig. 6 shows an alternative for the embodiment shown in Fig. 5;

Fig. 7 shows an LCD comprising a substrate with unidirectional conductivity and a substrate with optically active material;

Fig. 8 shows a cross sectional view of a substrate manufactured according to a further embodiment of the present invention;

Fig. 9 shows a cross sectional view of a sphere used in the manufacturing of a substrate as shown in Fig. 8;

Fig. 10 shows a schematic cross sectional view of a substrate as shown in Fig. 8 applied on top of an LC layer;

Fig. 11 shows a simplified electrical equivalent circuit for the assembly shown in Fig. 10;

Fig. 12 shows the electrical field distribution over the LC layer of Fig. 10 for variations in radius of the conductive spheres;

Fig. 13 shows the electrical field distribution over the LC layer of Fig. 10 for variations in the thickness of the insulation layer;

Fig. 14 shows a cross sectional view of a display device with a structure similar to the LCD shown in Fig. 4, in which the LC layer is replaced by an optically active layer;

Fig. 15 shows a cross sectional view of an alternative arrangement for the display device of Fig. 14;

Fig. 16 shows a cross sectional view of alternative arrangement of the display device of Fig. 15, using double funnel shaped pixels comprising a fluid with charged particles;

Fig. 17a and 17b show a cross sectional view of one pixel of a display device according to a further embodiment of the present invention, in deactivated and activated situation, respectively;

Fig. 18a and 18b show a cross sectional view of a pixel according to a further embodiment of the pixel shown in Fig. 17, in deactivated and activated situation, respectively; and

Fig. 19 a and 19b show a cross sectional view of an alternative embodiment of the pixel shown in Fig. 18, in deactivated and activated situation, respectively.

Fig. 1 shows a cross-sectional view of a substrate 1 manufactured according to a preferred embodiment of the present invention. The substrate 1 is a planar substrate, and comprises numerous conductive

columns 2 embedded in an insulating material 3. Although it is preferred that the conductive columns 2 are distributed over the substrate 1 in a regular pattern, a regular pattern is not required to give the substrate 1 the required characteristics of unidirectional conductivity. The insulating material ~~3 is provided such that a thin insulating layer 7 is provided on top of each conductive column~~ 2. The substrate 1 with unidirectional conductivity according to the present invention can be used in applications, in which no current is required to flow from a first surface of the substrate 1 to the opposite surface. For instance, the substrate 1 can be used in applications, in which an electrical field is used for control, as in controlling a liquid crystal layer.

Fig. 2 shows a phase in the production of a substrate 1 with unidirectional conductivity according to a preferred method. According to this preferred embodiment, a flat supporting structure 5 is provided, on ~~which a foil from a~~ first material 4, e.g. a conductive, UV sensitive material is produced. This can, e.g., be done by casting or spin coating the first material 4 onto the supporting structure 5. Following regular procedures, known per se, the first material 4 can be solidified, e.g. by thermal hardening or evaporation of solvents. The foil is subsequently exposed to UV radiation, using ~~a mask 6~~ to provide a pattern on the foil. The unexposed parts of the foil can be removed by using suitable solvents. As a result, a pattern of the first material 4 corresponding to the mask will remain on the supporting structure 5, e.g. a regular pattern of conductive columns 2. According to the present invention, a second material 3, in this case an insulating material, is applied on top of the conductive columns 2. The ~~insulating material will~~ fill the spaces between the conducting ~~columns 2~~, but according to the present invention, insulating material 3 is applied until a thin planar layer of the insulating material 3 is provided on top of the columns 2. After hardening the insulation material 3, the supporting structure 5 can be removed, resulting in the substrate 1.

Because one surface of the substrate consists of the insulation material 3, the substrate 1 has a certain rigidity enabling simple handling of the substrate 1, without the need for a supporting layer 5 during further processing of the substrate 1.

The structure of the resulting substrate 1, as shown in Fig. 1, with conductive columns 2 extending perpendicularly from one surface of the substrate 1 almost to the other side of the substrate 1, with only a small insulating layer on the other side, is very well suited for application in liquid crystal displays (LCD). Fig. 3 shows the electrical equivalent of one conductive column 2, the insulation layer 7 and a liquid crystal layer 8, driven by an electrical source 9. The height of the conductive column 2 is indicated by D1, the thickness of the thin insulation layer 7 by D2 and the thickness of the LC layer 8 by D3. Calculations of the electrical field strength show that in the LC layer 8, the electrical field equals

$$D3/(D2+D3) * U,$$

provided that the dielectric constant of the LC layer 8 and the insulating material 4 of the thin insulation layer 7 are substantially equal. When the thickness D2 of the insulation layer 7 is small compared to the thickness D3 of the LC layer 8, substantially all of the electrical field is concentrated in the LC layer 8 (the electrical field in the conductive column 2 being zero), allowing effective control of the LC layer 8.

In Fig. 4 an assembly 14 is shown of a substrate 1 manufactured according to the present invention, provided on a first side of an LC layer 8, with the insulating side of the substrate 1 contacting the LC layer 8. On the other side of the substrate 1, a number of control electrodes 10 may be provided, electrically connected to one or more of the conducting columns 2 of the substrate 1. On the second side of the LC layer 8, a thin insulating layer 11 is applied, after which a conductive layer 12 is applied covering the thin insulating layer 11. Finally, an insulating layer 13 is applied to the top of the assembly 14 to provide protection for the layers of the assembly 14. With the assembly 14 shown in Fig. 4, the LC layer 8 can be controlled by providing a voltage to one of the control electrodes 10, forming an LC Display. At the position of the control electrode 10, the conductive columns 2, which are in electrical contact with the control electrode 10, will provide the voltage up to the thin insulation layer 7. When the conductive layer 12 is held at ground potential, the LC layer 8 will alter its light transmission characteristics in the area between these conductive columns 2 and the conductive layer 12.

Preferably, the control electrode 10 is in electrical contact with a large number of conductive columns 2. The larger the number of conductive columns 2 per control electrode 10, the higher is the attainable resolution and the less vulnerable is the device for failing or missing conductive columns 2. This has the advantage that no alignment is required of the control electrodes 10 with respect to the other layers 1, 8 of the assembly. It also allows more margins as to the number of conductive columns 2 in the substrate 1 that actually conduct from the first surface to almost the second surface of the substrate 1. Finally, the distribution of the conductive columns may vary over the substrate 1, allowing more margins in the manufacturing of the substrate 1.

The presence of the thin insulation layers 7, 11 between the LC layer 8 and, respectively the substrate 1 and the planar conductive layer 12 prevents the possibility of short-circuit in case of pressure exerted on both sides of the LCD 14.

In an alternative embodiment of the method according to the present invention, the cavities are not provided by etching, but by laser beam evaporation. This method is illustrated in Fig. 5. Preferably, a first layer 15 of insulating material is provided, onto which a laser beam 17 can be focused. By controlling the intensity and duration of light pulses of the laser beam 17, the first material 15 can be evaporated to a predetermined depth of the layer, thereby forming cavities in the first material. When the material is evaporated in such a way, that a predetermined thickness of the first material 15 is left, the first layer remains self supporting, thereby obviating the need for a supporting structure or layer as in the embodiment described above. By filling the cavities with a conductive material 18, e.g. a conductive polymer, conductive columns 2 are formed extending from a first side of the substrate 1 to almost the opposite side of the substrate 1.

By using laser beam evaporation to provide the cavities in the first material 15, the steps of producing a suitable mask, exposing the first layer through the mask, developing the layer and etching the layer are no longer needed, resulting in a more simple and precise production method of the substrate 1.

The laser beam evaporation method can also be used to produce a substrate 1 in which the conductive columns 2 are formed extending

completely from the first side to the second side of the substrate 1. This further embodiment of the present invention is shown diagrammatically in Fig. 6. For this embodiment of the present invention, the laser can be used as a laser beam cutter, locally evaporating all material of the first layer 15. After this laser beam cutting step, a layer of first, insulating material results in a certain pattern, provided with through-holes in a predetermined pattern. These through-holes can be filled with a second, conductive material 18, e.g. a conductive polymer, resulting in the substrate 1 with unidirectional conductivity. Preferably, a supporting structure 5 is used to facilitate production of a flat first substrate surface.

In two further alternative embodiments, the second material 18 used to fill the cavities in the layer of first material 15 is an optically active material, such as a liquid crystal (LC) material. Preferably, in these embodiments, the number of conductive columns 2 per square unit in the substrate 1 is smaller than the number provided in the embodiments to provide a unidirectional conductive substrate 1.

As a further alternative, the optically active material is a photochargeable material, which converts light impinging on the photochargeable material into an electrical charge. An even further alternative uses photoconductive material, of which the resistance is locally reduced where light impinges.

By combining the substrate 1 with unidirectional conductivity and a substrate 1' with optically active material, it is very simple to produce an LCD 14 as shown in Fig. 7. This figure also shows that it is preferred that the concentration of conductive columns 2 in the substrate 1 with unidirectional conductivity to be higher than the concentration of LC cells 2' in order to enable a proper control of the LCD by the associated control conductors 10. Both substrates 1, 1' can be provided with or without an insulating surface, i.e. all substrates can be manufactured according to any of the embodiments described above, as the LC material of the LC cells 2' is sensitive to the electric field across it. The use of the substrate 1' with the LC cells 2' will lead to a more precise definition of the display field associated with each control electrode 10, as compared to the LCD 14 shown in Fig. 4.

The LCD 14 manufactured as described with reference to any of the above mentioned embodiments shows a large degree of flexibility with

respect to display size, shape and pattern. The control electrodes 10 can be applied at a later production stage. Only at the final stage when the LCD 14 is completed, the control electrodes 10 have to be applied, defining the eventual appearance and characteristics of the LCD 14.

In a still further embodiment of the method according to the present invention, a substrate 1 with unidirectional conductivity is made with a structure as shown in Fig. 8. The substrate 1 is formed by conductive spheres 20 suspended in an insulating material 3. This substrate 1 or foil can be used in applications, in which the resolution and sharpness of the unidirectional conductivity is less important, e.g. in larger scale applications. Also, this substrate 1 can not be utilised in applications requiring DC-conductance, but is well suited for applications in which an electrical field has to be applied locally.

The first step of manufacturing the substrate 1 according to this embodiment is the manufacturing of small spheres 20 from a conductive material 21, preferably a conductive polymer. In order to prevent electrical short-circuit between individual spheres 20, the spheres 20 are coated with a thin layer of insulating material 22, as illustrated in Fig. 9. The thickness of the insulating layer 22 affects the characteristics of the substrate 1, as will be discussed below.

The spheres 20 with the insulating layer 22 are, preferably, distributed homogeneously in a liquid polymer. By applying manufacturing processes specific to the liquid polymer used, a planar substrate 1 is formed, e.g. by casting, UV-hardening, thermal hardening or evaporating solvents.

The substrate 1 can be used e.g. as an interface layer to control an optically active layer, such as an LC layer 8, in a manner comparable to the LCD-assembly 14 discussed above. Fig. 10 shows a simplified diagram of the structure of the substrate 1 manufactured according to this embodiment in combination with a liquid crystal layer 8. In this drawing, r is the thickness of the insulation layer 22 of each sphere 20, R is the radius of the sphere 20, D is the total thickness of the substrate 1 and d is the thickness of the liquid crystal layer 8. Fig. 11 shows a simplified electrical equivalent circuit of the substrate 1 and the LC layer 8. When a voltage source 9 is used to drive the LC layer 8 with ground connected to the LC layer

8 and the positive voltage connected to the top surface of the substrate 1, the voltage at various positions in the substrate 1 and over the LC layer 8 can be calculated, as well as the electrical field. The electrical field in the LC layer 8, which is important for controlling the optical characteristics of the LC layer 8, can be expressed as

$$D4/(D1+D2+D3+D4) * U,$$

provided that the dielectric constant of the LC layer 8 and the insulating material 4 of the thin insulation layer 7 are substantially equal. In this formula, D4 is equal to the thickness d of the LC layer 8, D1 is the distance between the top two spheres 20 in the substrate 1 (equal to 2r), D2 is the distance between the middle and lower sphere 20 (equal to 2r), and D3 is the distance between the lower sphere 20 and the top of the LC layer 8 (and equal to r). When D4 is large compared to D1...D3, i.e. when the LC layer 8 has a large thickness d compared to the thickness r of the sphere insulation 22, the major part of the electrical field will be concentrated in the LC layer 8, enabling an effective control of the display. In Fig. 11, M denotes the dimension of the conductive spheres 20, in which no electrical field is present.

Calculations with the simplified model described above, of the distribution of the electrical field over the LC-layer 8 in the assembly of substrate 1 and LC layer 8 as shown in Fig. 11 as a result of a voltage applied by an electrical source 9 have been made for variations of substrate thickness D, sphere radius R, insulation layer thickness r and thickness d of the LC layer 8. The measurement points are related to the thickness D of the substrate 1, in which the first measurement point is located directly opposite the electrical connection of the electrical source 9 to the substrate 1, and the next measurement points are located at distances equal to multiples of the substrate thickness D from the first measurement point. The results are shown in Fig. 12 for variations in radius R of the conductive spheres 20, and in Fig. 13 for variations in the thickness r of the insulation layer 22. The results show that the electrical field has a peak directly under the electrical connection of the electrical source 9 and rapidly decreases for the other measurement points. This substrate therefore can be used to locally apply an electric field, e.g. in an LCD.

display device 23, 25. In an alternative embodiment, the small spheres 27 may be given a preferential direction. Applying an electric field in one direction will then cause the spheres 27 to align in one direction, while without an electrical field the spheres 27 will be aligned in another direction. The small spheres 27 and the optically active layer 24 may be manufactured according to the method published in European patent EP 0 540 281 of Xerox. Fabrication of a display device 23, 25 as described above is greatly simplified by using the substrates 1 with unidirectional conductivity according to the present invention.

In a further embodiment of the display device 23, 25 according to the present invention, the optically active layer 24, may comprise microcontainers 29 (dimensions in the order of ten microns) filled with a fluid of a first colour and charged particles with a second colour (dimensions in the order of microns). The microcontainers 29 may be comprised in the optically active layer 24 in a similar arrangement as the small spheres 27, as described above. Because of the electrostatic charge of the particles, the particles will move to one side of the microcontainer 29 under the influence of an electric field. When the particles have moved to one side of the microcontainer 29, their electrostatic charge will result in a new steady state because the particles will stay on the same place against the wall of the microcontainer 29. This enables to form a permanent image on the display device 23, 25, making it very suitable as electronic paper. As in the previous embodiment, the particles may be given a preferential position. Applying an electric field in one direction will then cause the particles to move to one side of the microcontainer 29, while without an electrical field the particles will remain in the other side. The operation and a manufacturing method for the microcontainers 29 and a layer containing microcontainers 29 is described in P. Drzaic et al., "A Printed and Rollable Bistable Electronic Display", SID 98 Digest, pp. 1131-1134.

In a further embodiment of a display device 23, 25 according to the present invention, the optically active layer 24 is formed by an electrocapillary sheet, containing numerous capillaries from one side of the sheet to the other, filled with a polar fluid. Under the influence of an electric field in the electrocapillary sheet, the fluid will move in a predetermined direction, thereby enabling the

formation of an image on one side of the display device. The polar fluid may have different colours in separate capillaries to be able to form a coloured image. The electrocapillary sheet is described in e.g. EP-A-0 806 753 from Xerox.

In a fourth embodiment of the display device 23, 25 according to the present invention, the structure of the display device 23, 25 is again identical to the previous embodiments. In this embodiment, the optically active layer 24 is formed by a foil or plate provided with double funnel shaped pixels 28 perpendicular to the foil or plate, as indicated in Fig. 16. The two funnels forming a pixel 28 are connected to each other at the small ends and are filled with a fluid. In the fluid electrically charged particles are dispersed. Under the influence of an applied local electrical field, the charged particles in the fluid are directed to one of the funnels of a pixel 28, thereby allowing the formation of an image. The foil or plate with double funnel shaped pixels 28, forming the optically active layer 24, is described in European patent EP-0 783 163 from Xerox.

A fifth embodiment of the display device 23, 25 according to the present invention uses electrically driven chemomechanical polymer gels. These polymer gels absorb or reject fluids when an electrical current flows through them and as a result the polymer gel will expand or diminish its volume. A cross sectional view of one pixel 30 of a plurality of pixels 30 forming a display device 23, 25 is shown in Fig. 17a and 17b. Examples of electrically driven chemomechanical gels are described in Y. Osada et al., "A polymer gel with electrically driven motility", Nature, Vol. 355, no. 6357, pp 242-244, 16 January 1992.

More in general, electrically driven chemomechanical polymer gels can be used to alter the optical properties of a device provided with a flexible optical member, e.g. a flexible lens, of which the optical properties may be altered by electrically driven chemomechanical polymer gel provided on the perimeter of the flexible lens.

In the fifth embodiment, for each pixel 30 of the display device 23, 25, a small sphere 31 made of flexible, conductive material is positioned between and electrically connected to a first substrate 1 with conductive channels and a foil 32 coated with electrically driven chemomechanical polymer gel. The foil 32 coated with the gel is positioned a short distance from a second substrate 1' with conductive

channels and a conductive fluid 33 is provided in the open space between the first substrate 1 and the second substrate 1'. On both the first substrate 1 and the second substrate 1', respective control electrodes 26, 26' are electrically connected. In this embodiment, an electrically driven chemomechanical polymer gel is used that rejects fluid when submitted to an electric current. The first situation, without an electrical current flowing through the pixel, is shown in Fig. 17a. When a current flows through the pixel 30, the electrically driven chemomechanical polymer gel rejects the fluid, causing the polymer gel to contract. Because only one side of the foil 32 is coated with the polymer gel, the foil will consequently bend, thereby pressing the flexible, conductive sphere 31 against the first substrate, as shown in Fig. 17b. When the fluid 33 has a first colour and the flexible conductive sphere 31 a second colour, the appearance of the pixel will change from the first colour to the second colour.

A further embodiment of the display device 23, 25 according to the present invention also uses an electrically driven chemomechanical polymer gel. Instead of a foil 32 coated with the electrically driven chemomechanical polymer gel, this embodiment uses cylinders 35 of electrically driven chemomechanical polymer gel in contact with the second substrate 1', as shown in Fig. 18a. In this embodiment, an electrically driven chemomechanical polymer gel is used that can absorb fluid 33 when a current flows through the pixel. Consequently, when a current is applied to the control electrodes 26, 26' of the pixel 30, the polymer gel cylinder 35 expands and presses the flexible conductive sphere 31 against the first substrate 1, as shown in Fig. 18b.

In a seventh embodiment of a display device according to the present invention, the flexible conductive spheres 31 of the sixth embodiment are replaced by a flexible conductive coating 37 on top of the polymer gel cylinder 35, as illustrated in a cross sectional schematic diagram in Fig. 19a and 19b. The operation of this embodiment corresponds to that of the sixth embodiment, as shown in Fig. 18a and 18b.

When the fluid 33 in the display device 23, 25 using the electrically driven chemomechanical polymer gel is an electrolytic fluid 3, it is possible to generate currents in the layer containing the pixels 30 by applying a voltage to the control electrodes 26, 26'.

The currents are then generated by electron and ion movements in the electrolytic fluid 33 under the influence of the electrical field in the pixel 30. The electrically driven chemomechanical polymer gel will then expand or decrease under the influence of the induced current until a steady situation is reached. In this case, it is possible to use substrates 1, 1', of which one surface consists entirely of insulating material 3.

By pressing a coloured flexible sphere 31 or coating 37 to the first substrate 1, the colour of the sphere 31 or coating 37 will appear on the face of the display device 23, 25 with a high degree of colour saturation.

C l a i m s

1. Method of manufacturing a substantially planar substrate with a predetermined substrate thickness, having a first substrate surface and a second substrate surface extending substantially in parallel to the first substrate surface, and being formed of at least a first and a second material having substantially different conductivities, such that conductive channels are formed substantially perpendicular to the substrate surfaces, and the conductivity perpendicular to the substrate surfaces, as measured over a predetermined area, is substantially larger than the conductivity parallel to the substrate surfaces, characterised in that the method comprises the steps of:

- providing a layer of the first material (4; 15) with a predetermined thickness, having a first surface forming the first substrate surface;

- forming cavities in the first material (4; 15) in a predetermined pattern across a second surface of the first material (4; 15), in which the cavities extend in a direction substantially perpendicular to the first surface over a predetermined depth; and

- applying the second material (3) on the second surface of the first material (4) until the cavities are at least filled, thereby forming the second surface of the substrate (1).

2. Method according to claim 1, characterised in that

- the first material is an insulating material (15) with a thickness equal to the substrate thickness;

- the cavities are manufactured to extend to a depth smaller than the thickness of the first material (15).

3. Method according to claim 2, characterised in that the second material is a conductive material (18).

4. Method according to claim 2, characterised in that the second material is an optically active material (18).

5. Method according to claim 1, characterised in that the second material is an insulating material (3) and the method further comprises the steps of:

- applying the first material (4) on a supporting structure (5) with a thickness of less than the substrate thickness;

- manufacturing the cavities such that the depth of the cavities is equal to the thickness of the first material (4);

- applying the second material (3) until the substrate reaches the predetermined thickness;

- forming the substrate (1) by removing the supporting structure (5).

6. Method according to claim 5, <u>characterised in that</u> the first material is a conductive material (4, 18).

7. Method according to claim 5, <u>characterised in that</u> the first material is an optically active material (4, 18).

8. Method according to one of the claims 5 through 7, <u>characterised in that</u> the first material (4) is UV sensitive and the method further comprises the steps of forming the cavities in the first material (4) by applying a mask (6) corresponding to the pattern over the first material (4), exposing the first material (4) to UV radiation, and etching the first material (4).

9. Method according to one of the claims 1 through 7, <u>characterised in that</u> the cavities in the first material (15) are formed by laser beam (17) evaporation.

10. Method of manufacturing a substantially planar substrate with a predetermined substrate thickness, having a first substrate surface and a second substrate surface extending substantially in parallel to the first substrate surface, <u>characterised in that</u> the method comprises the steps of:

- producing spheres (20) of a first, conductive material (21);

- coating the spheres (20) with a thin layer (22) of a second, insulating material;

- providing an insulating polymer (3), and distributing the coated spheres (20) homogeneously in the insulating polymer (3);

- producing the substrate (1) from the polymer (3) containing the spheres (20),

such that the electric field distribution on the first surface of the substrate (1) has a local maximum value directly opposite a locally applied voltage on the second surface of the substrate (1), which electrical field decreases with distance from the local maximum.

11. Display device (23) comprising at least a first substrate (1) manufactured according to one of the claims 1 through 10, and a layer of conductive material (12) substantially parallel to the first substrate (1), the display device (23) further comprising an optically active layer (8; 24) positioned between the first substrate (1) and the conductive layer (12), and at least one control electrode (10) electrically connected to a surface of the first substrate (1) opposite the optically active layer (24), thereby enabling the provision of a local electrical field over the optically active layer (8; 24).

12. Display device according to claim 11, <u>characterised in that</u> the layer of conductive material (12) is formed by a second substrate (1'), also manufactured according to one of the claims 1 through 10, and in that the display device (25) is provided with a plurality of further control electrodes (10') on a surface of the second substrate (1') opposite the optically active layer (24).

13. Display device according to claim 11 or 12, <u>characterised in that</u> the optically active layer (24) comprises dipole spheres (27) with semispheres of a first and second colour, respectively, which dipole spheres (27) can be aligned by the local electrical field, such that the semispheres of the first or second colour are aligned in the same direction.

14. Display device according to claim 11 or 12, <u>characterised in that</u> the optically active layer (24) comprises microcontainers (29) containing charged particles, in which the charged particles are moveable to one side of the microcontainer (29) under the influence of the electric field.

15. Display device according to claim 14, characterised in that the microcontainers (29) comprise charged particles of one colour suspended in a fluid of a second colour.

16. Display device according to claim 14 or 15, characterised in that the charged particles are arranged to move to one side of the optically active layer (24) in the absence of an electrical field.

17. Display device according to claim 11 or 12, characterised in that the optically active layer (24) comprises an electrocapillary sheet with electrocapillaries, in which a polarized fluid is contained in the electrocapillaries, which fluid can be displaced under the influence of an electric field.

18. Display device according to claim 11 or 12, characterised in that the optically active layer (24) comprises double-funnel shaped pixels (28) comprising two funnels, in which narrow parts of the funnels are connected to each other, in which the pixels (28) are filled with a fluid, containing electrically charged particles, which can be displaced through the funnels under the influence of an electric field.

19. Display device according to claim 18, characterised in that the charged particles have one colour and the fluid has a second colour.

20. Display device comprising a first and a second substrate manufactured according to one of the claims 1 through 10, in which the first and second substrate are positioned substantially parallel to each other, an optically active layer is positioned between the first and second substrate, and a number of conductors are provided on the outside surfaces of the first and second substrate, thereby enabling the provision of a local electrical field in the optically active layer, characterised in that the optically active layer (24) comprises a number of pixels (30) comprising at least one flexible member (31, 37) of a first colour, at least one expandable member (32, 35) comprising at least an electrically driven chemomechanical polymer gel, and a fluid (33), which expandable member (32, 35) is arranged to

press the flexible member (31, 37) against the second substrate (1) under the influence of the local electrical field.

21. Display device according to claim 20, characterised in that

- the flexible members are formed by a layer of flexible conductive spheres (31) arranged next to each other in electrical contact with the second substrate (1);

- each expandable member comprises a foil (32) with a coating of electrically driven chemomechanical polymer gel on one side, positioned such that the polymer coated side is in proximity of the first substrate (1') and the other side of the foil is in contact with at least one flexible conductive sphere (31);

in which the polymer gel will absorb the fluid (33) in the absence of an electrical field and will discard the fluid (33) in the presence of an electrical field, thereby bending the foil (32) and pressing the at least one flexible conductive sphere (31) against the second substrate (1).

22. Display device according to claim 20, characterised in that

- the flexible members are formed by a layer of flexible conductive spheres (31) arranged next to each other in electrical contact with the second substrate (1);

- the expandable members are formed by flexible conductive polymer gel cylinders (35) in electrical contact with the first substrate (1') and extending in the direction of the second substrate (1);

- a conductive fluid (33) of a first colour is present between the cylinders (35) and the second substrate (1);

in which the polymer gel cylinder (35) will discard the fluid (33) in the absence of an electrical field and will absorb the fluid (33) in the presence of an electrical field, thereby expanding and pressing the flexible conductive spheres (31) against the second substrate (1).

23. Display device according to claim 20, characterised in that

- the expandable members are formed by flexible conductive polymer gel cylinders (35) in electrical contact with the first

substrate (1') and extending in the direction of the second substrate (1);

- a conductive fluid (33) of a second colour is present between the cylinders (35) and the second substrate (1);

- the flexible members are formed by conductive coatings (37) of a second colour on top of each flexible conductive polymer gel cylinder (35);

in which the polymer gel cylinder (35) will discard the fluid (33) in the absence of an electrical field and will absorb the fluid (33) in the presence of an electrical field, thereby expanding and pressing the conductive coating (37) against the second substrate (1).

24. Use of an electrically driven chemomechanical polymer gel to alter optical properties of a device provided with a flexible optical member.

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Fig 1

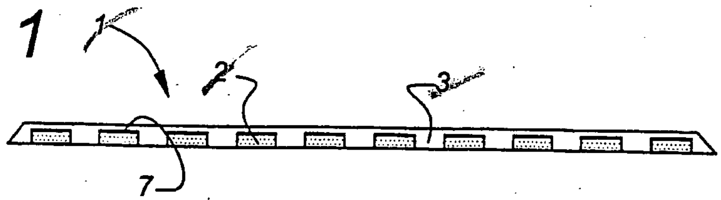


Fig 2

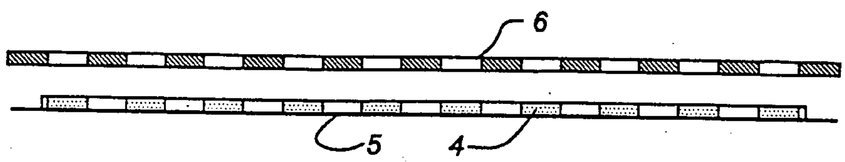


Fig 3

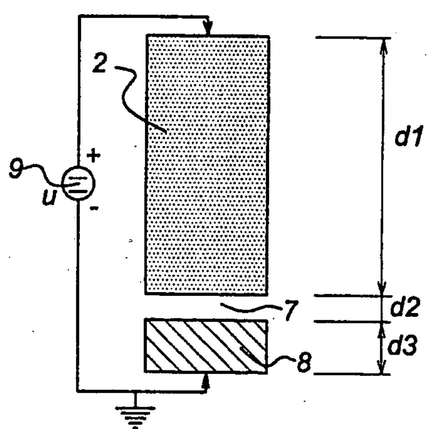


Fig 4

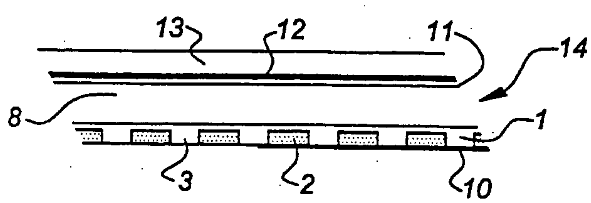


Fig 5

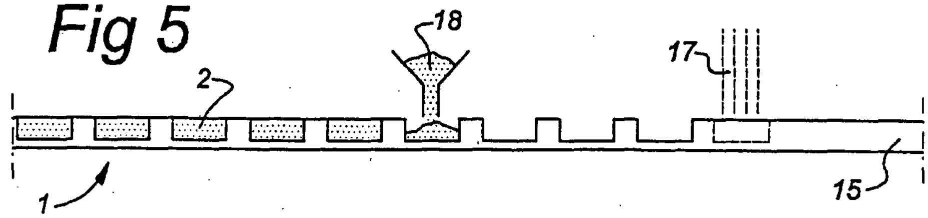


Fig 6

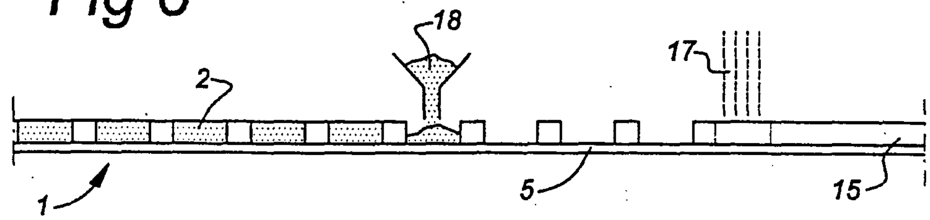


Fig 7

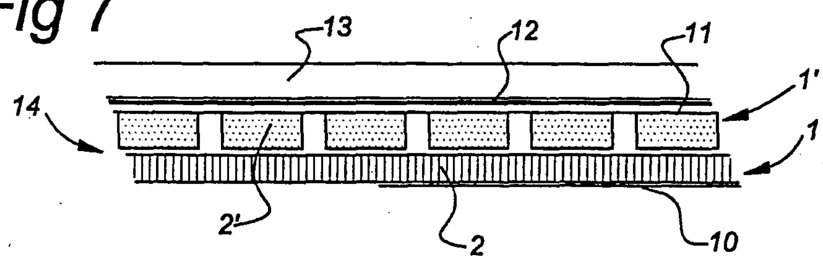


Fig 8

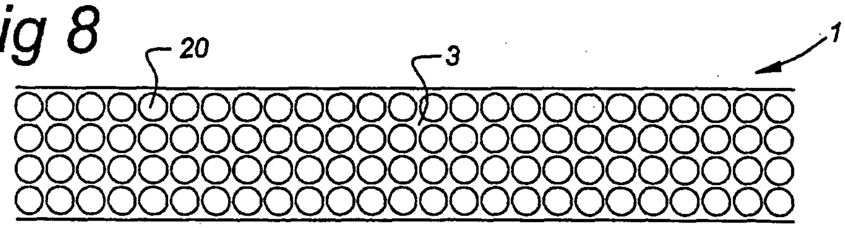


Fig 9

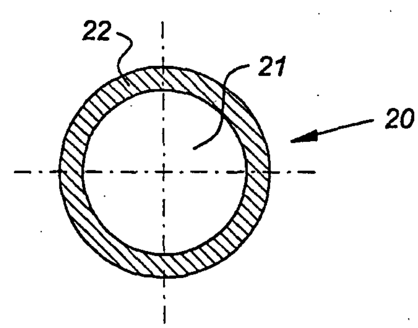


Fig 10

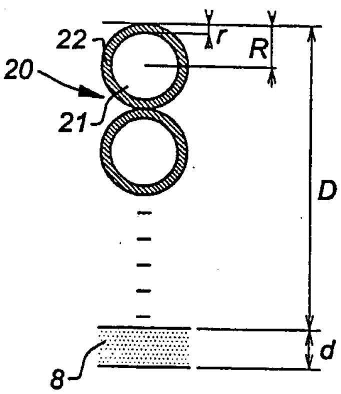


Fig 11

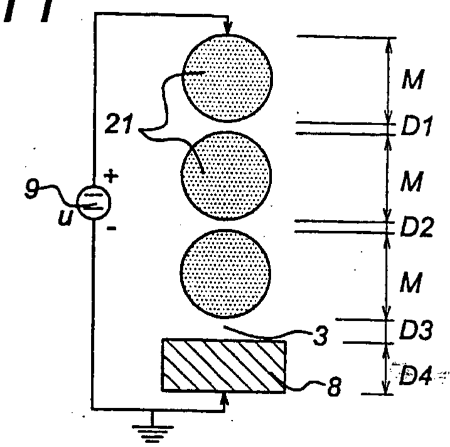


Fig 12

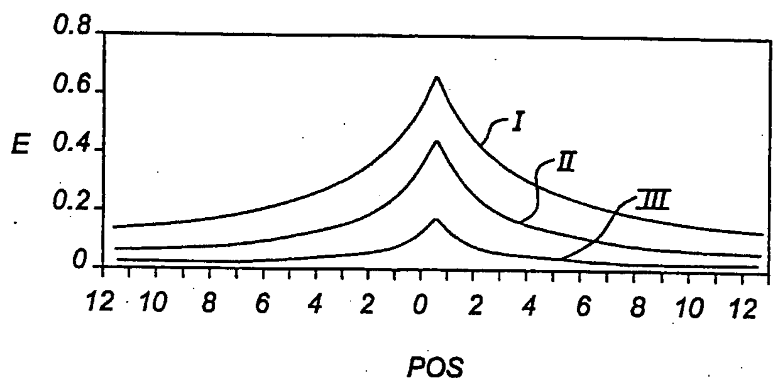
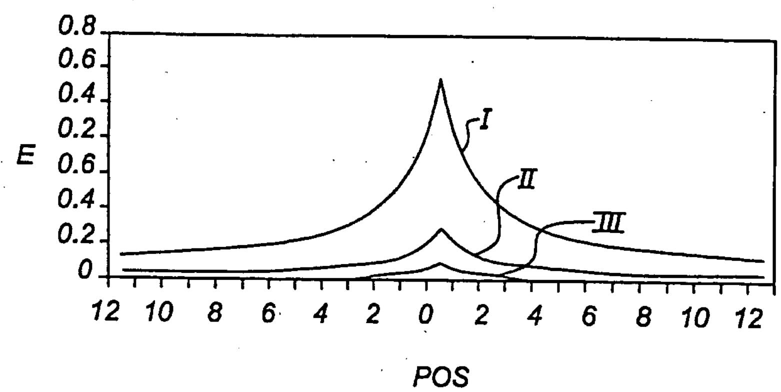


Fig 13



In Fig. 12, results of the electrical field distribution are shown for three different values of the sphere radius, with constant substrate thickness D = 50 μm, LC layer thickness d = 2 μm and insulation layer thickness r = 0.1 μm. Line I shows the result for a sphere radius R = 5 μm, line II for R = 2 μm and line III for R = 0.5 μm. The results show that a larger sphere radius R will lead to a higher local electrical field.

In Fig. 13, results of the electrical field distribution are shown for three different values of the insulation layer thickness r, with constant substrate thickness D = 25 μm, sphere radius R = 0.5 μm and LC layer thickness d = 2 μm. Line I shows the result for insulation layer thickness r = 0.1 μm, line II for r = 0.5 μm and line III for r = 2 μm. The results show that a larger insulation layer thickness r will lead to a lower local electrical field. Calculations for variations in substrate thickness D and LC layer thickness d show that a higher electric field is obtained for a larger LC-layer thickness d and for a smaller substrate thickness D. This is obvious, as the electrical field is distributed over the substrate 1 and the LC layer 8 according to their respective dielectric dimensions.

The substrate 1 manufactured according to this latter embodiment of the present invention can be used in applications in which the requirements with respect to the resolution and sharpness of the unidirectional conductivity may be less strict, e.g. applications of the substrate 1 in display devices with large dimensions.

As an alternative, the substrate manufactured according to this embodiment of the present method can be used as dielectric layer to produce capacitors with a large capacity.

Fig. 14 shows a cross sectional view of a display device 23 with a structure similar to the LCD 14 shown in Fig. 4, in which the LC layer 8 is replaced by an optically active layer 24. This display device may also be used as electric paper, as the different layers can be made very thin, resulting in a flexible paper-like display. The operation of the display device 23 is similar to the operation of the LCD 14, discussed with reference to Fig. 4. In Fig. 14, the optically active layer 24 is shown comprising numerous small dipole spheres 27. The optically active layer 24 comprising small dipole spheres 27 will be discussed in detail below.

As an alternative, a display device 25 can be constructed as shown in Fig. 15. In this display device 25, the optically active layer 24 is sandwiched between two substrates 1, 1' according to the present invention, in which the insulating surfaces of the substrates 1, 1' are in contact with the optically active layer 24. On the other surfaces of the substrates 1, 1', a plurality of control electrodes 26, 26' can be electrically connected to the substrates 1, 1' in order to control the optical properties of the optically active layer 24. By applying a voltage between two control electrodes 26, 26' on each side of the display device 25, the optically active layer 24 is exposed to a local electrical field. In Fig. 15, the optically active layer 24 is shown comprising numerous microcontainers 29. The optically active layer 24 comprising microcontainers 29 will be discussed in detail below.

Similar to the optically active material used in an embodiment to manufacture the substrate 1 as already described above, the optically active layer 24 may consist of e.g. LC material, such that the electrical field applied is converted into optical transmission characteristics of the optically active layer 24. As an alternative, the optically active layer 24 may be provided as a layer of photochargeable material. In this case, the control electrodes 10, 26, 26' are used to pick up the electrical signal from the optically active material. In an even further alternative, the optically active layer 24 may be provided as a layer of photoconductive material, of which the resistance is reduced when light impinges on the display. This resistance change may be picked up by the control electrodes 10. 26, 26'.

In the embodiments shown in Fig. 14, the optically active layer 24 comprises small spheres, indicated by reference numeral 27, of which the two halves have a different colour. The spheres 27 are constructed as electrical dipoles. Because of the unidirectional conductive properties of the substrates 1, 1', an electrical field can be generated locally in the optically active layer 24 by applying a voltage on the control electrode 10 in the embodiment in Fig. 14 or between two control electrodes 26, 26' on both sides of the substrates 1, 1' in the embodiment shown in Fig. 15. Because of the dipole character of the small spheres 27, the spheres 27 will align with the local electrical field, enabling the formation of an image in the

Fig 14

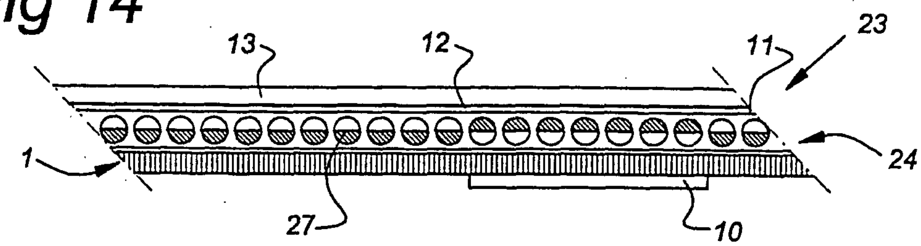


Fig 15

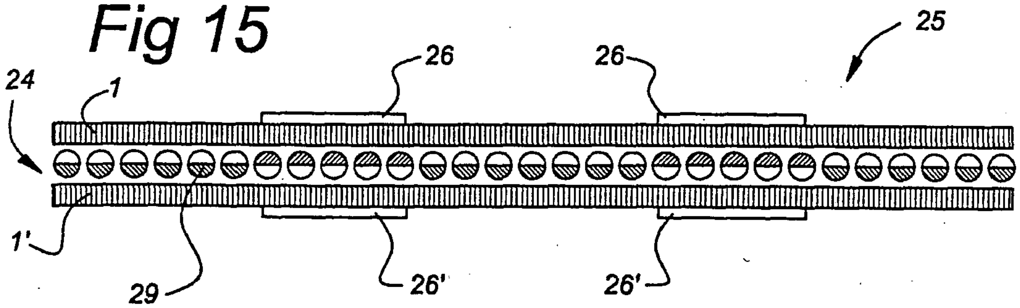


Fig 16

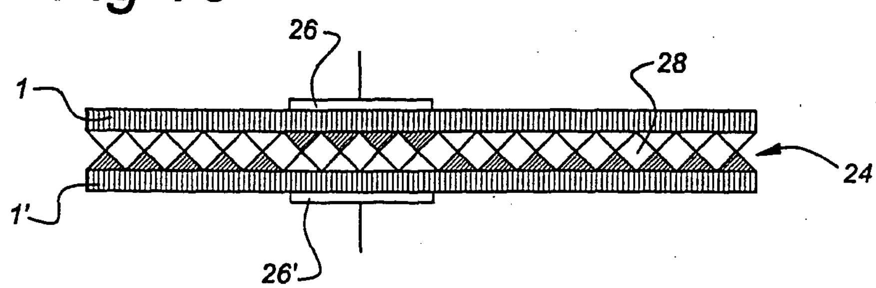


Fig 17a

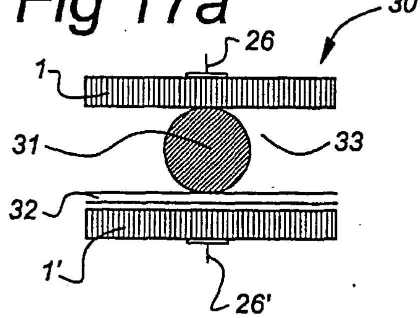


Fig 17b

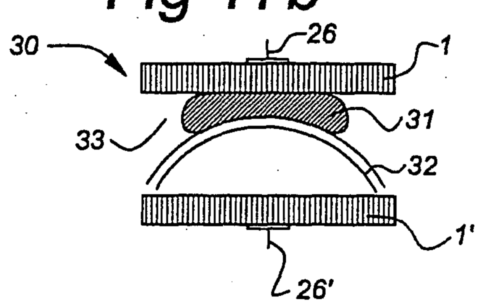


Fig 18a

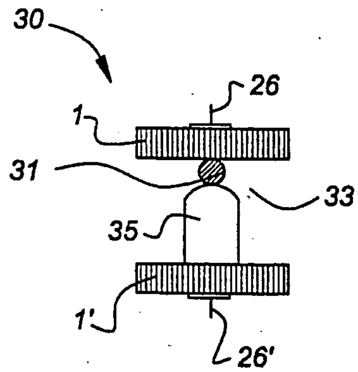


Fig 18b

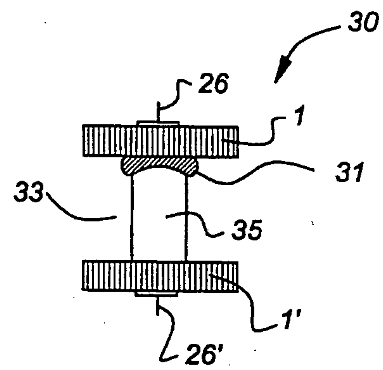


Fig 19a

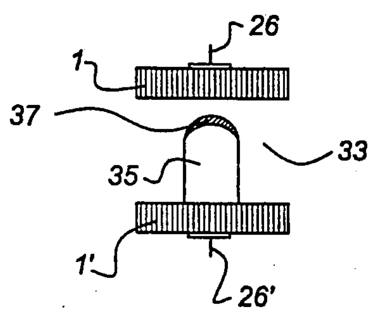
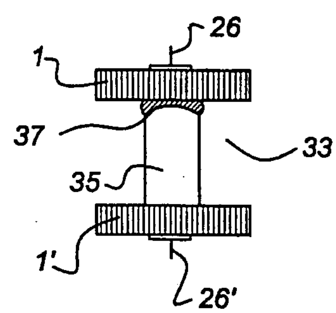


Fig 19b



INTERNATIONAL SEARCH REPORT

International Application No
PCT/NL 98/00712

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L23/532 G02F1/1345

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01L G02F H05K G09F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 608 129 A (TAMAMURA TOSHIAKI ET AL) 26 August 1986 (1986-08-26) column 1, line 7 - line 28 column 2, line 32 - column 3, line 67 column 6, line 1 - line 13 column 14, line 45 - column 15, line 24; figures 1A-1D,8 ---	1-11,20, 24
A	US 5 805 424 A (PURINTON DONALD L) 8 September 1998 (1998-09-08) column 2, line 55 - line 65 column 8, line 17 - line 58; figures 4,6,13 ---	1,10,11, 20,24
A	US 5 123 849 A (DEAK FREDERICK R ET AL) 23 June 1992 (1992-06-23) the whole document ---	1,10,11, 20,24

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Date of the actual completion of the international search	Date of mailing of the international search report
3 August 1999	11/08/1999

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

International Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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Form PCT/ISA/210 (continuation of second sheet) (July 1992)

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